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ABSTRACT

This report examines ways of providing technician training in the operating principles of robotic devices. The terms "robotics" and "robotic arms" are first defined. Some background information on the principal features of robotic arms is given, including their geometric arrangement, type of actuator used, control method, and software and teaching modes. Three types of problems in implementing courses for technician training in industrial automation are considered: the availability of suitable equipment at acceptable cost, the lack of guidance on suitable teaching material, and the training of teaching staff. Finally, the problem of devising suitable curricula is discussed. Appendixes include a glossary of terms, a bank of suggested objectives intended to provide a suitable technical background for engineers and technicians using robotic devices in industry, outlines of three course units/modules prepared by selecting from the objectives banks, and a list of references. (YLB)

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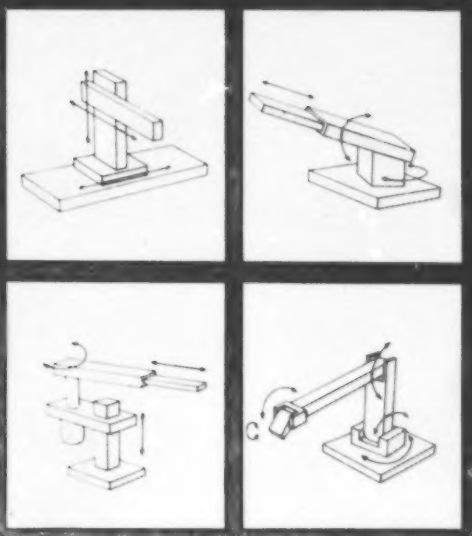

ROBOTIC ARMS

A CONTRIBUTION TO THE CURRICULUM

AN OCCASIONAL PAPER

July 1984

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Dear Sir/Madam

ROBOTIC ARMS - A CONTRIBUTION TO THE CURRICULUM

Attached is a brief report on a comparatively new area of technology. As with other FEU publications in Information Technology, rapid changes in the equipment available, make this document almost out of date as it goes to print. Nevertheless, colleges need to identify in any technology those principles which remain important irrespective of change.

This report in its earlier sections, introduces the concept of robotic devices and their software; gives some guidance on equipment costs and identifies the staffing required. The authors then develop a bank of curriculum objectives which make up a core from which programmes for technicians and others can be built. The Preface makes the point that although many robotic arms are now appearing, the terminology and configurations show signs of stabilising; thus the important principles of robotic technology can be identified.

It is hoped that this document*, with its background information and bank of objectives, will enable colleges to devise curricula to suit the needs of students and employers.

Yours faithfully

Jack Mansell

JACK MANSELL
Chief Officer

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* We hope soon to publish a further document dealing more generally with Robotics and its curricular implications.

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ROBOTIC ARMS

A CONTRIBUTION TO THE CURRICULUM

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PREFACE

In recent years, ***robotic arms*** *have found their way into college engineering laboratories. Most engineering departments, if they do not already possess one, are considering the purchase of this device; and college and curriculum bodies alike are developing ways of introducing robotics into the curriculum.*

At the time this project was commissioned robots were a rarity in colleges – soon they will be commonplace. We are conscious that certain aspects of this report, notably ***Table 1****, which lists currently available robotic arms, are in danger of being out of date by the time it is published. However, it is possible that we have reached a stage where the terminology and configuration of robotic arms are stabilising, and it is hoped that colleges with an interest in robotics will find this summary of the 'state of the art' in early 1984 to be of value.*

Although the report refers specifically to the need for 'technicians' to be familiar with robotic devices, the objectives described in ***Appendix B*** *may be used with a wide variety of students. Examples are given in* ***Appendix C*** *of modules suitable for post-experience short courses as well as for conventional technician courses.*

Probably the most cogent argument for the introduction of robotic arms into FE curricula as devices in their own right is that they 'provide an excellent illustration of most of the major principles underlying automation, particularly the industrial application of microprocessors' (Paragraph 38). New technology generally requires the integration of a wide range of disciplines, including mechanics, electronics, production, computing and maintenance – the robotic arm is a good example of a multidisciplinary topic area which facilitates this integration.

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SUMMARY

The increasing use of robotic devices in industry implies the training of substantial numbers of personnel, particularly technicians, in the technology of robots. The report examines the problems of introducing technician training courses in robotics. The suitability of low-cost robotic arms for technician training is considered, and some of the arms which are available are compared in cost, in construction, and in the facilities which they offer. It is suggested that these arms can be used for the broad-based introductory courses which are considered in the report. Teaching material suitable for such courses is outlined in the form of a bank of objectives which can be used selectively, in accordance with the student background and needs, and examples of course modules are included. Although the teaching of the more specialist courses must make considerable demands on staff, it is suggested that teaching requirements at the introductory level may be met largely by integrating existing material from a variety of disciplines. Colleges with mechanical & electrical engineering and computing, departments should be able to offer introductory units which include robotics without any substantial staff retraining commitment.

INTRODUCTION

1. The automation of production is generally considered to be one of the most important of the current developments in technology, and this obviously has considerable training implications. A wide spectrum of industrial personnel will increasingly require some knowledge of automation techniques, ranging from the detailed expertise of the engineers responsible for design to the broader view of the manager and production engineer. This report is concerned with some of the technician-training implications of the new technology.

2. For the present purpose the term *technician* is meant to include technically-trained staff other than professional engineers. Training at craft level in robotics is being included in *City and Guilds* courses (***Appendix D Ref. 1***). The skills required for the new technology tend to blur the distinction between craftsmen and technicians.

3. The microprocessor, on which the present 'revolution' in industrial automation depends, poses a major challenge to technician training. The flexibility and 'intelligence' which is offered by the microprocessor is well represented by the industrial robot. This provides an excellent example of, and a suitable training in, the technology of modern industrial automation. The general objective of the report is to explore ways of providing technician training in the operating principles of robotic devices.

4. The problems of implementing such courses fall into three main areas, each of which is considered in the report:

(a) the availability of suitable equipment at acceptable cost;
(b) the lack of guidance on suitable teaching material;
(c) the training of teaching staff.

The first of these needs is now being met by the appearance of an increasing selection of low-cost robotic arms, and one objective of this report is to assess the use of these arms for technician training. Much of the teaching material which is needed is already available, but is spread over a wide range of different courses in mechanical and electrical engineering, control, microprocessors, and other topics. A second major objective is the extraction from this of suitable course material. A third objective is a consideration of staffing, and staff training, requirements.

1. WHAT IS MEANT BY ROBOTICS?

5 The term ***robot*** is one with many connotations, and its use here is restricted to industrial applications. There is nothing novel about devices which perform complex industrial manufacturing tasks entirely automatically, and the process which started with the Jacquard loom led to a proliferation of automated production facilities, of which the manufacture of electric light bulbs is a typical example. More recently, the development of numerically-controlled machine tools opened the way to major advances. But the even greater change which is now occurring is in the appearance of devices whose behaviour is far more flexible, or 'intelligent', than any of their predecessors. One development is the combination of the microprocessor with the general-purpose manipulator. Most of these manipulators have at least a superficial resemblence to the human arm, and ***robot arms*** is a convenient generic name for this type of industrial automation device. Their range may be extended by mounting them on vehicles which travel around a storage area, and this may change both the appearance and the tracking method, but is essentially no more than a means of increasing the workspace by extending the movement.

6 ***Robotic arms*** form only one example of the equipment of a modern automated factory, in which entire assembly lines can (and increasingly will) be controlled in an hierarchical manner with micro-processors, or computers, at each of the various control levels. But robotic arms make a major contribution, and they illustrate most of the major principles underlying modern automated production techniques – particularly the combination of feedback and power ***actuators*** under the direction of an operating program executed by a digital processor. They also provide an excellent illustration of design and maintenance problems. Thus the arms exemplify the wider problems of modern industrial automation.

7 A high degree of flexibility is not always necessary or desirable, and the term ***robot arm*** embraces a considerable diversity of products. At one extreme the simplest of the pick-and-place arms have only a very limited range of movements *(ie* ***degrees of freedom****)* or scope for control, and programming may be merely a matter of setting mechanical stops or limit switches. (Although even in these 'low technology' devices the microprocessor now offers advantages, including price.) While there is no agreement on nomenclature, *medium technology* arms are generally distinguished from *low technology* by having more degrees of freedom, especially in 'hand' movements, by the degree of control of the path taken between any two points, and by the ease with which they can be 'taught' or re-programmed. Arms designed for paint-spraying and welding are common examples. Applications such as these require a smooth and closely-defined motion (*ie* continuous-path lifting and loading tasks in which the only requirement is to transfer something from one point to another. The most modern and elaborate *high technology* arms incorporate further refinements in programming and in the use of feedback from optical and other sensors, giving increased accuracy and adaptability. Generally, the objective is to make the arms more 'intelligent', so that they respond to changes in the working environment instead of merely following a pre-set program of movements.

2. ROBOTIC DEVICES

8 Robot arms vary greatly in their geometric arrangement and type of actuator used, as well as in the complexity of control and in programming capability. Some of the major features are listed below, with the object of identifying the principal aspects of interest to the teacher.

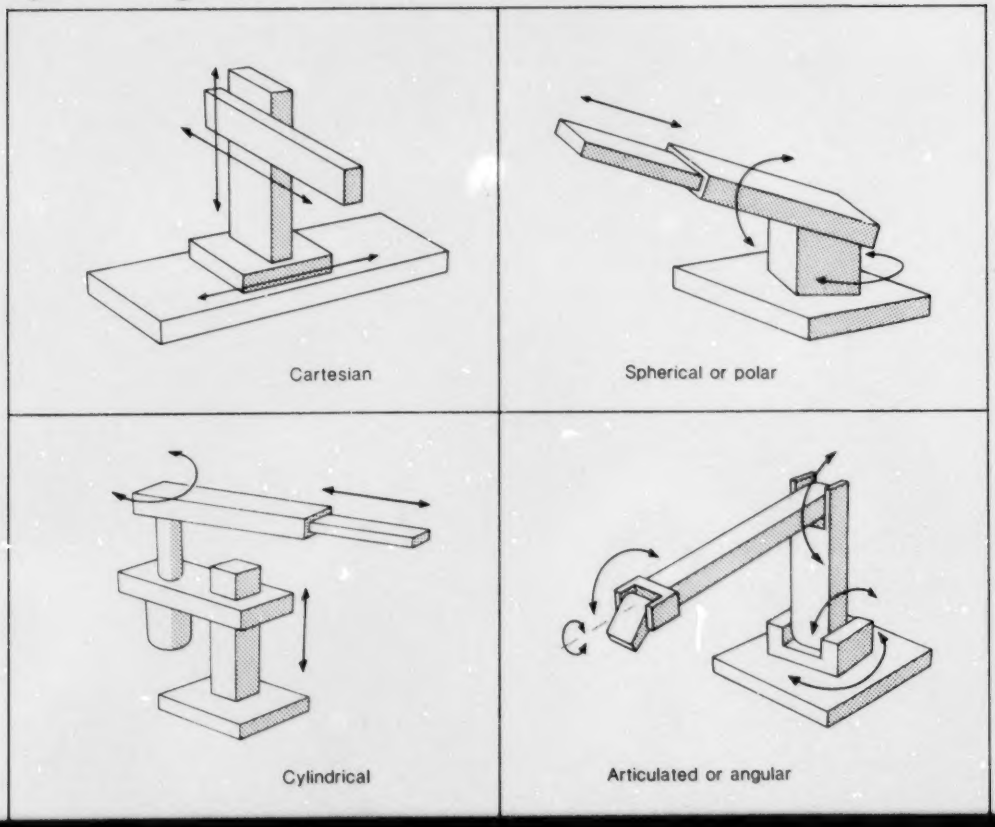
Geometry

9 A popular form of geometry closely models that of the human arm, giving rotation at the 'waist', and angular movement at the 'shoulder', 'elbow' and 'wrist', possibly together with other degrees of freedom such as additional axes of rotation at the 'wrist'. Angular motion gives a relatively simple and robust construction, but greatly complicates the program needed for a simple linear operation such as 'lift straight up'. It is unsuited to some industrial operations, particularly those in which the access is limited (*eg* through some sort of tunnel). Here linear motion may be necessary, and this may be used for all three axes, or combined with other motions. ***Figure 1*** illustrates some of the possibilities. Linear motion tends to lead to a more difficult and expensive design as the arm load is increased.

Actuators

10 The arm may be driven electrically, pneumatically, or hydraulically, or by any combination of these on different axes, or even on the same axis. Hydraulics gives the greatest force-per-unit-size, so that it is particularly suitable for large arms and heavy loads. Pneumatics provides the cheapest source of power for small actuators, and finds its main application in *pick-and-place* devices with simple control requirements. Electric drives take various forms. Electromagnetic devices give low forces and torques, so that some form of gearing is usually essential. This increases the complexity and cost and generally means that electrical actuators are rotary in form, even when a linear displacement is required. The larger electric motors are usually d.c. (with or without permanent magnet excitation) and these are simple to control. They may be designed with low inertia for rapid response. The ***stepper-motor*** is a lower-torque device which has been manufactured only in small sizes, but it is particularly easy to drive under the control of a microprocessor, and gives accurately-controlled displacements without the use of feedback. In consequence it provides one of the most popular drives for small arms, and stepper-motors are currently being increased considerably in size and power. They may be used on larger arms to give accuracy of final positioning, together with an hydraulic or pneumatic actuator driving rapidly through the major part of the displacement.

Figure 1 ***Arm geometries***



Control method

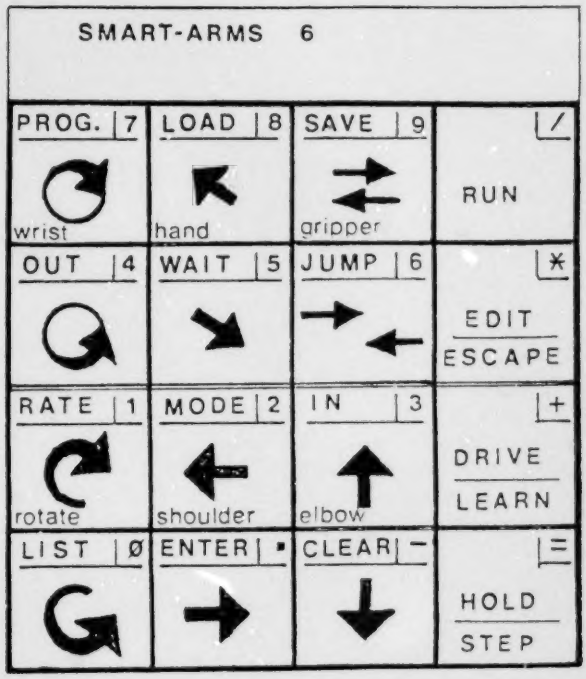
11 The absence or provision of feedback as a method of arm control, and the feedback method adopted, is one of the major factors controlling the performance specification and the complexity and cost. The term *feedback* refers to any method of detecting the arm position and using the information to control the arm motion. The stepper-motor is one of the few actuators which gives good accuracy without the need for feedback, and this is one of the reasons for its popularity. It is driven by pulses, each of which moves it by a small step, and the requisite number of pulses rotates it through precisely one revolution, so that the simple process of a count of the driving pulses is sufficient to establish the actuator (although not necessarily the arm) position accurately. Perhaps the simplest method of control is that used in the *pick-and-place* type of arm in which a switch or valve cuts off the power when the arm arrives at the desired position. In these low technology, or *low order,* arms the microprocessor has control only of the sequence of movements. Most other actuators require some method of feedback, and the variants are in the form which this takes.

12 Any attempt to simulate the human arm demands control over the speed of operation of each axis separately, and a means of preventing overshoot at the end point, which implies some form of control of acceleration and deceleration rates. This is generally easier to achieve with electric motors and actuators than with hydraulic and pneumatic devices. A further level of control is achieved by the continuous-path robots, such as those used for welding, which can be instructed not only to go from point A to point B, but to follow a precisely-defined path between A to B, and to follow it at a velocity which is specified at each point along the path. This demands not only very close control of the arm dynamics, but also the transfer and storage of a considerable amount of information.

Software and teach modes

13 One of the major variables is the degree of 'intelligence' of the device (that is, the flexibility of operation and complexity of the software). A limited-sequence device without feedback offering only a small number of steps in the operating sequence makes a correspondingly small demand on memory capacity and requires only simple programming techniques. More complex control sequences require larger memories to accommodate the data, high-level languages to provide more flexible communication, and a greater variety of techniques for 'teaching' the arm elaborate sequences of operation. The more complex sequences must include conditional responses which will allow the device to adapt to conditions which it encounters, such as the absence of the parts to be picked up.

***Figure 2* Smart-Arms control keypad layout**



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14 One of the most important aspects of the language is the way in which the arm may be 'taught' a sequence of instructions. One way is to key in the information. This can be done by preparing a program listing which specifies the path data, or by pressing keys which are pre-programmed to control the arm directly, giving responses such as 'move up' or 'open gripper'. These can be used to drive the arm by trial-and-error through the desired sequence and pressing a 'learn' key when each step has been completed satisfactorily. A typical keypad is shown in ***Figure 2.*** Continuous-path robots require a more direct form of 'teach' mode in which either the arm itself, or a model of it, is taken manually along the desired operating path. This method of instruction is also useful in point-to-point robots which allow manual operation, since the quickest way of moving a robotic arm between two points is by hand, particularly when the arm is small and slow.

Table 1: Features and prices of some low-cost robotic arms

Prices generally exclude VAT

MANUFACTURER	ARM	DRIVE TYPE (1)	DRIVES (2)	MOTION (3)	ARM PRICE £ (Sept 1983) (4)		ADDITIONAL COSTS £	CONTRCL (5)		
					KIT	ASSEMBLED		MANUAL	ON BOARD COMPUTER	EXTERNAL COMPUTER
INTELLIGENT ARTIFACTS (CAMBRIDGE)	SMALL ARM	SM	6	ANG		350	150			EXC
COLNE ROBOTICS (TWICKENHAM)	ARMDROID	SM	6	ANG	200	320	100	INC		EXC
CYBER ROBOTICS (CAMBRIDGE)	CYBER 3	SM	6	ANG		650				EXC
HEATHKIT	HERO	SM	M			2,495		INC	INC	
L.J. ELECTRONICS (NORWICH)	ATLAS	SM	6	LIN+ ANG		1,750		INC	INC	EXC
MITSUBISHI (RICKMANSWORTH)	RM 101 MOVEMASTER	SM	6	ANG		1,140				EXC
PENDAR (EBBW VALE)	PLACEMATE	P	5+	ANG		15,000		INC	INC	
POWERTRAN (ANDOVER)	P 101 P 102	H	6	ANG	600		250	INC	INC	EXC
	M 101	H	M	ANG	1,175	1,950		INC	INC	EXC
REMCOM		ES	4	ANG		175				
SYKE (PORTSMOUTH)	MINIMOVER 5	SM	6	ANG		1,680				EXC
SYSTEMS CONTROL	SMART ARM	ES	6	ANG		1,500		INC		INC

Footnotes

(1) **ES** – electro servo; **SM** – stepper motor; **H** – hydraulic; **P** – pneumatic

(2) **M** – mobile arm

(3) **ANG** – angular; **LIN** – linear

(4) All prices are approximate

(5) **INC** – included in price
EXC – suitable for computer control but computer price not included.

3. EQUIPMENT COSTS

15 There is now a wide choice of small, low-cost arms designed for teaching purposes, as well as an increasing range of industrial arms which are sufficiently cheap to bring them within the larger teaching budgets. These provide sufficient mechanical capability to illustrate many of the important principles of industrial handling tasks. The facilities for interfacing with a computer provides the potential for devising and storing complex operating cycles, although teach-mode programming may be tedious, and the computer interface may limit both the operating speed and the control of the operating path when this requires the simultaneous operation of more than one axis. The suitability of small robotic arms for teaching purposes will obviously depend on the aims of the course. If these include the use and maintenance of industrial arms, then arms of this type must form an essential part of the practical work, but even the larger educational laboratories with several industrial arms find that cheap, small units meet an important teaching need. They are simple and safe to use, and provide better opportunities for individual practical work since they can be purchased in greater numbers, and require less supervision.

16 A survey of available arms is given ***(Appendix D** Ref. 2)* and should be consulted for comparisons and comments. Some of the better-known arms and the facilities which they offer are listed in ***Table 1*** to illustrate the range. The equipment divides conveniently into three different price categories, each of which is considered in more detail in the following paragraphs.*

17 Six-axis stepper-motor arms can be purchased for as little as £200 in kit form, and fall generally in the range £250 – £1000. They have a performance capability which is entirely adequate for many teaching functions, and are found useful even when larger arms are available. A major limitation, besides limited load, workspace, and working life, is the lack of any illustration of feedback principles. The speed limitation is an advantage in the introductory teaching stages, but can make more advanced teach-mode programming unnecessarily tedious. Another important limitation is that of accuracy, partly because of constructional limitations, but also because one way of reducing cost is to increase the size of the motor step.

18 Three examples of arms in the £1000 – £2000 price range are included in the table. One (LJ) is a larger and more powerful stepper-motor arm, whilst the other two both incorporate feedback. The *Powertran* arm uses hydraulic linear actuators driving elbow-type joints, an arrangement which is mechanically simple, but gives a large variation in displacement force with arm position. The feedback signals are obtained from simple position transducers consisting of coils wound round the hydraulic cylinders. These detect the position of the operating pistons.

19 The third example of arms in the medium-price range is the *Smart-Arms* series, with electric servo-motor drives. The performance, in particular the maximum operating speed, is sufficient for the manufacturers to offer it for light industrial purposes, and this greatly increases its potential whilst, on the other hand, making it less suitable for introductory teaching since some safety precautions are desirable. The electric servo-motor illustrates a drive method of increasing industrial importance, and avoids the possible nuisance of oil spillage from hydraulic actuators. But the most important advantage of the servo-motor drive is the much closer control over the arm functioning than that offered by the comparatively crude on-off hydraulic switching. The high operating speed is one measure of this improvement.

20 The small arms which are available in kit form vary greatly in ease of assembly. Stepper-motor arms are generally Meccano-like in construction and can be easily assembled. The associated electronic circuitry consists of pulsing circuits mounted on printed circuit boards, which are easily damaged when soldering, but can otherwise be constructed and tested by technicians of limited electronics experience. Generally the financial savings in purchasing a kit instead of a ready-assembled arm are small, although the hydraulic arm manufactured by *Powertran* is one exception. This takes correspondingly longer to assemble than stepper-motor arms.

*Prices quoted refer to September 1983

4. MICROCOMPUTERS AND SOFTWARE

21 The small robotic arms most suited to teaching purposes may be supplied with various microprocessor and microcomputer facilities, or none at all. The relative advantages and disadvantages of each arrangement, particularly in cost, will depend on what additional facilities are available, to what extent it is desirable to use these for a dedicated task such as arm control, and the effort in interfacing and in the preparation of software which is contemplated.

22 Although an arm can be controlled entirely from a computer using a high-level language, this will greatly reduce the operating speed, and will generally impose other limitations. A more effective combination is obtained by using dedicated drive circuitry to provide the immediate control functions, and a microcomputer to store both the users' programs and the operating system which is needed to program in a high-level language. Some arms may be purchased without the computer, some include one 'on board', and others are provided with a separate non-dedicated microcomputer complete with keyboard and display monitor. Clearly the last is likely to be the most expensive solution, although the complete package may well be offered at a lower price than the total cost of the components when purchased separately, and it will normally include a full range of software. Two factors are to be considered when comparing complete systems with separate units. On the one hand, a system computer may be available for other purposes when not in use with the arm. On the other hand, the flexibility of separate units may be illusory if equipment such as a computer is subject to conflicting teaching demands. Arms with dedicated 'on board' microcomputers are most representative of industrial devices, and provide the necessary computer power at least cost.

23 Most of the arms on offer today are provided with some essential operating software, supplied either in a cassette or in a ***ROM***. The software generally provides for alternative modes of operation, one of which gives direct manual control of the arm from the computer keyboard. The advantage of using the computer instead of a manual control box (which may be provided as well) is that the movements can be stored, and the sequence repeated. The arm can then be 'taught' an operating sequence either by moving it through the sequence and instructing it to 'learn' the necessary co-ordinates, or by giving those co-ordinates as keyboard data. Such software forms an essential part of any useful arm installation, and is therefore important in any course on robotics. The time available for programming does not allow the development of software, even if this were desirable, and indeed the software will normally represent a considerable investment of programming effort, much of it at assembler level.

24 Arms which are controlled by a general-purpose computer will generally have software provided by the arm manufacturer for some specified type of computer. This may allow greater flexibility in the modification and development of software than in a dedicated computer in which the software is in *ROM*. Another possible disadvantage of the dedicated machine is that the keypad provided may only allow for a limited range of specific commands. However, most of these arms make provision for interfacing an external computer.

25 Information about the provision of microprocessors and microcomputers is included in ***Table 1***. Most of the available arms include at least some form of drive circuitry, such as is needed to provide coded pulses to stepper-motors. Many include a microprocessor, together with a keyboard giving manual control of the arm by pressing keys to operate the different drives. All of these can be interfaced with a suitable computer, such as the BBC machine, which is provided with the necessary input-output ports, and a magnetic tape or disc drive to store programs.

5. STAFFING

26. Most colleges with ***Mechanical & Electrical Engineering*** and ***Computing*** departments already teach most of the basic material which is needed, and the problem of offering courses in robotics is essentially that of integrating these different technologies into the new sphere of interest. Clearly the first requirement is sufficient interest, motivation and leadership, and this is most likely to be provided by a mechanical or production engineer. However, robotics is essentially a multi-disciplinary subject of considerable appeal to electrical, as well as mechanical, engineers, so that it is both possible and desirable to include a number of staff with a range of different backgrounds. Some retraining of staff may be necessary to obtain a broad understanding of the inter-relationship between disciplines, and this may help to provide a focus for the broadening of staff interest which is demanded by modern production technology.

27. The additional staff expertise and updating will depend on the type of course under consideration. Whereas a full-time specialist robotics course will obviously make considerable demands on the staff, the major need is to include elements of robotics in a wide range of engineering courses, and this can be met with relatively little retraining and updating.

28. A major element of staff training is some experience of the industrial use of robots. The number of device manufacturers is limited, but many more firms are either using robotic devices or planning their use, and it is probably the user, rather than the manufacturer, who has most to offer. Experience suggests that, because of the novelty of robot arms, firms introducing them into their production processes are very willing to discuss their experiences and problems, and encourage an interest in them. Most are anxious to encourage and assist the provision of suitable training courses for the personnel needed to operate the arms.

29. Information on robotics is now becoming available in more convenient form, particularly textbooks. A brief list is included in ***Appendix D.*** Some commercially-supported courses on robotics have published teaching material at a moderate price *(**Appendix D** Refs. 12/13).* Other teaching aspects are discussed in ***Appendix D*** *Ref. 11* . There are many journals, meetings, colloquia, exhibitions, etc. which are helpful in providing material and guidance.

30. The provision of new equipment requires adequate support from non-teaching staff. One of the advantages of assembling arms from kits is that it provides a measure of technician training, which is a major factor in the use of cheap arms which are not supported by manufacturers' courses. The technician resources of most colleges are likely to provide the expertise needed to assemble and maintain the small arms, provided that there is sufficient experience of microprocessors.

6. ROBOTICS CORE CURRICULUM

31. Robotics forms a part of the wider field of industrial automation, which is the concern of production engineers, managerial staff, and the like with an interest in robots as components in a production system, rather than as stand-alone devices. The training needs of such staff are under consideration in the ***FEU/ BTEC Robotics Project (RP119) (Appendix C** Ref. 3).* The more limited group which is considered here comprises technicians concerned with the installation, operation, maintenance and repair of robotic devices. This group requires a wide knowledge of the different aspects of robot technology (including mechanical and electrical devices, control methods and the use of microprocessors and computers) but not the very specialised knowledge of the arm designer. They will require detailed information about the specific robot arms for which they are responsible, but this information will usually be available for industrial-type arms in the form of brief, intensive courses and literature offered by the arm manufacturer.

32. A major feature of technician training courses in robotics is the range of devices and principles which they must include. No great depth of knowledge is generally required, however. The needs can be contrasted with those of a technician specialising, for example, in electrical engineering, who may require a good deal of information about large electrical generators, but little on electrical actuators or servo-motors.

33. A bank of objectives intended to describe the range of robot arm technology is given in ***Appendix B.*** Most students can be expected to have a knowledge of some aspects of this material, depending on their background. If, for example, the material is integrated into a mechanical engineering course, then the teaching requirements are different from those presented in an electrical engineering department. Likewise, electrical departments will differ in the extent to which topics such as control and microprocessors are treated. This will depend partly on the level at which the course is offered. The material is suitable for selective treatment at a variety of levels. The intention, therefore, has been to attempt a comprehensive set of objectives from which a selection can be made according to the level of the course and the background of the students.

34. One example of a 60-hour unit into which a selection of the objectives has been incorporated is given in ***Appendix C.*** This is a unit intended principally for electrical and electronics technicians in a full-time HD course. A second example of an introductory half-unit in a post-experience course, aimed at students drawn from a wider background, is also given in ***Appendix C.***

35. Experience at Gwent College suggests that there is at present more interest in robotics as a single topic than as one component of a broader course. The outlines of two 40-hour evening courses are given in ***Appendix C.***

36. Although technicians are probably the largest single group requiring a broad view of robot technology, the teaching objectives are of interest to many engineers and others concerned with robot installations, or wishing to know more about the subject. Among the other categories of industrial personnel likely to be closely involved in robotic applications are:

(a) managers and other non-technical staff who need only a general understanding of the capabilities of robot arms, and the advantages and disadvantages of different types;

(b) technical personnel at engineer or chief technician level responsible for the robot arms installations, and software and other engineers associated with them.

Some of the needs of such groups can be met from the objectives bank by selection. A course suitable for group (a) for example, can be constructed from ***Appendix B*** objectives *A.1, B.2,* and *K.11,* some parts of *C.3, D.4* and *E.5,* together with an expanded version of *I.9* and *J.10.* However, the requirements of production managers must necessarily also include topics outside the province of the engineer.

CONCLUSIONS

37. The emphasis which is now being placed on robotics in industry demands an extended programme of training in the skills needed for robotic devices. Technician training is particularly important.

38. Robotic arms and manipulators form only one example of factory automation equipment, but they make a major contribution. They also provide an excellent illustration of most of the major principles underlying automation, particularly the industrial application of microprocessors. *[Paras 5 – 7]*

39. Some background information on the principal features of robotic arms is given in the report, together with references to other sources of information. *[Paras 8 – 14]*

40. Most industrial-type robot arms are too expensive for use in teaching institutions other than those with a specialist interest in robotics, but a range of small, low-cost arms is now available. Some of these are compared with price and capability in ***Table 1.*** Experience with a few of these suggests that they meet most of the needs of technician training of the type considered here, at an acceptable cost. The provision of suitable software by the manufacturer is an important consideration. *[Paras 15 – 25]*

41. Although the robot technology draws on a wide range of expertise, the primary need is for introductory courses, most of the expertise for which is already available in colleges with interests in mechanical and electrical engineering and computing. It is suggested that the problem is essentially one of integration of existing material into the new subject area, so that only a limited staff retraining, or updating, is needed to teach the introductory type of course. *[Paras 26 – 30]*

42. The problem of devising suitable curricula is discussed. A bank of suggested objectives is provided, together with examples of possible course units. The objectives list is intended to be treated selectively, according to the requirements of the course and the students' background. Although the material which is suggested was prepared for technician training, sections of it can be adapted for use in familiarisation courses aimed at much wider audiences. *[Paras 31 – 36]*

APPENDIX A

GLOSSARY OF TERMS

ACTUATORS

The electric, hydraulic, or pneumatic devices providing the mechanical power needed to produce a controlled movement.

DEGREES OF FREEDOM

The number of independent movements, or the number of arm joints and actuators.

HARDWARE

A device, and associated equipment, as distinct from software.

ROM

Read-only silicon-chip memories generally used to provide operating software.

ROBOTIC ARM

A manipulator capable of grasping and moving objects under the control of a computer or microprocessor.

SERVO-MOTOR

An electric motor giving rapid response to changes in input signal.

SOFTWARE

The program or programs controlling the operation of a computer or microprocessor.

STEPPER-MOTOR

An electric motor moving in discrete steps in response to digital signals.

APPENDIX B

INDUSTRIAL ROBOTICS – A BANK OF OBJECTIVES

● *The following is intended to provide a suitable technical background for engineers and technicians using robotic devices in industry. All important technical aspects are included, but are treated only in sufficient depth to provide the background needed by the user, not the designer. The material can be treated selectively to obtain courses of different length and depth of study, and to meet the requirements of students with different backgrounds.*

● *The material is presented in the form of teaching objectives each of which should be understood to be prefixed by the words 'The expected learning outcome is that the student . . .'.*

[A] EVOLUTION OF ROBOTICS

1. Describes the development of programmable robotic arm devices.
   - 1.1 Defines the term *robotics* as a sub-class of automation.
   - 1.2 Lists the advantages and disadvantages of present day robots relative to the human operator.
   - 1.3 Identifies typical applications of dedicated machines controlled by a hard-wired logic controller.
   - 1.4 Explains the development of programmable devices including the step-sequence controller and the programmable logic controller (P.L.C.).
   - 1.5 Lists the advantages of a programmable sequence machine in a control situation where the machine requirements may change.
   - 1.6 Defines the robot as a mechanical manipulator with several degrees of freedom capable of being programmed for more than one task.
   - 1.7 Distinguishes between non-programmable, limited-sequence robots and playback robots.
   - 1.8 Distinguishes between robotic arms and other types of robotic device.
   - 1.9 Identifies the developments of microelectronics which have made low cost, multi-function robotic devices practical.

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[B] ROBOT ARCHITECTURE

2. Describes the physical structure of a robotic arm.
   - 2.1 Defines the terms *arm geometry, axes, degrees of freedom, actuator* and *controller.*
   - 2.2 Describes the basic structure of a robotic arm device with up to six degrees of freedom.
   - 2.3 Names and describes various types of joint and arm motion eg waist, shoulder, elbow wrist (pitch, yaw, roll), grasp.
   - 2.4 Defines the following co-ordinate systems: (a) *cartesian;* (b) *cylindrical;* (c) *polar;* (d) *revolute.*
   - 2.5 Sketches typical arm arrangements using the different co-ordinate systems defined in 2.4.
   - 2.6 Explains the relationship between the co-ordinate system used and the effective working space of the robot.
   - 2.7 Describes the relative advantages and disadvantages of each co-ordinate system by reference to a particular robot task.
   - 2.8 Explains how the working space can be extended by giving the robot mobility.
   - 2.9 Explains the influence of arm structure on dynamic performance, accuracy and speed.

[C] POWER DRIVES AND ACTUATORS

3. Describes and compares common actuator types used in robotic arm devices.
   - 3.1 Explains the functions of the basic components of an hydraulic system – eg pumps, actuators, motors, control valves, reservoirs, filters, etc.
   - 3.2 Draws a circuit diagram for a simple hydraulic control circuit using standard schematic symbols.
   - 3.3 Lists the factors affecting the choice of hydraulic power for use in a robotic device – eg application, power requirements, environment, energy storage for peak loading, cost of device and associated maintenance etc.
   - 3.4 Explains the functions of the basic components of a pneumatic system – eg compressor, actuator, control valves, reservoirs, filters, driers etc.
   - 3.5 Draws a circuit diagram for a simple pneumatic control circuit using standard symbols.
   - 3.6 Lists the factors affecting the choice of pneumatic power for use in robotic devices – eg application, cost, power requirements, environment, cleanliness, disposability, safety, etc.
   - 3.7 Describes the features of solenoid operated valves and their usefulness in electrically controlled hydraulic and pneumatic circuits.
   - 3.8 Recalls the essential difference between a.c. and d.c. power supplies and between single-phase and three-phase a.c. systems.
   - 3.9 Describes the basic operational and performance characteristics of three-phase and single-phase induction motors.
   - 3.10 Describes the basic operational and performance characteristics of d.c. servo-motors.
   - 3.11 Describes the basic power supply requirements and associated control gear for the motors of 3.9 and 3.10.
   - 3.12 Describes the principle of operation of one type of permanent magnet stepping motor.
   - 3.13 Explains the basic principle of stepping motor control/driver circuits.
   - 3.14 Lists some of the relative advantages and disadvantages of stepping motors compared with other electrical drives for robotic applications – eg ease of control using digital techniques, lack of speed and power.
   - 3.15 Draws a circuit diagram for a simpler motor control circuit using standard symbols.
   - 3.16 Selects a particular type of actuator to meet a given task specification.
   - 3.17 Lists the factors affecting the choice of electric power for use in a robotic device.

[D] GRIPPERS AND MANIPULATORS

4. Describes the importance and nature of suitably designed grippers.
   - 4.1 Lists common methods of handling such as mechanical grippers, hooks, scoops or ladles, electromagnets, vacuum cups, adhesive devices, sockets, electrostatic devices.
   - 4.2 Outlines the uses of the various methods in 4.1 for such tasks as handling castings and forgings, molten metals, liquids or powders, thin sheets, delicate objects, materials or paper, corrosive materials.
   - 4.3 Outlines the important parameters to be considered when choosing or designing a manipulator—eg shape, weight, temperature, accessibility etc. of load.
   - 4.4 Chooses a suitable manipulator design for a given task.
   - 4.5 Describes the development of multi-function, hand-like grippers.
   - 4.6 Explains how the gripper may be given a crude sense of 'touch'.

[E] CONTROL SYSTEM ELEMENTS

5. Describes the use of open-loop and closed-loop systems in the control of robotic arm actuators.
   - 5.1 Describes the operation of a limited sequence robot as a point-to-point machine, the sequence of which is controlled by mechanicl stops or limit switches.
   - 5.2 Describes the operation of hydraulic and pneumatic actuators as basically ON-OFF devices.
   - 5.3 Describes typical electronic drivers for solenoid valve controllers.
   - 5.4 Lists the advantages of limited sequence robots, including good accuracy, low cost, high speed etc.
   - 5.5 Lists the disadvantages of limited sequence robots, including limited number of steps, small number of limb articulations, difficulty in changing sequence etc.
   - 5.6 Describes typical pick-and-place applications for limited sequence robots—eg die casting, press loading etc.
   - 5.7 Distinguishes between an open-loop and a closed-loop control system.
   - 5.8 Describes the application of stepping motors to open-loop position control systems.
   - 5.9 Describes the features of stepping motor control that renders feedback unnecessary.
   - 5.10 Explains the importance of pulse counting for stepper drive positioning and the possible need for 'lost-pulse' detection.
   - 5.11 Describes, in block diagram form, a typical stepping motor control system of a type suitable for the control of an arm joint.
   - 5.12 Explains what is meant by the term 'Servomechanism'.
   - 5.13 Describes the use of feedback to give position and velocity control in a servo system.
   - 5.14 Describes, in block diagram form, the action of a hydraulic servo.
   - 5.15 Describes, in block diagram form, the principal components of an electrically driven analogue servo system.
   - 5.16 Explains the essential features of the pulse width modulation technique of motor control.
   - 5.17 Describes, in block diagram form, the principal components of a digital servo system.
   - 5.18 Explains why a memory device is essential to machine flexibility.
   - 5.19 Outlines the process of 'teaching' the robot by driving the arm manually and storing its co-ordinates in memory.
   - 5.20 Lists some of the advantages of programmable robots.
   - 5.21 Describes typical programmable robot applications—eg welding, spraying, batch production etc.

[F] DATA ACQUISITION AND CONVERSION

6. Describes some common data acquisition transducers and the signal conditioning necessary for their use.
   - 6.1 Distinguishes between analogue and digital signals.
   - 6.2 Outlines the need for D-A and A-D conversion in hybrid systems.
   - 6.3 Explains, in block diagram form, the essential characteristics of D-A and A-D converters.
   - 6.4 Describes the basic characteristics of typical position and proximity detectors such as potentiometers, photo electric devices, optical encoders, synchros, infra red detectors, variable inductance and variable capacitance devices, acoustic devices.
   - 6.5 Describes the basic characteristics of typical touch, force and torque sensors, including pressure transducers, strain gauges, micro-switches, piezoelectric devices, touch switches.
   - 6.6 Outlines the basic power supply, signal level adjustment and signal conditioning requirements of devices listed in 6.5.
   - 6.7 Explains the term 'noise' as applied to data acquisition.
   - 6.8 Explains the use of electrical filters to reduce the adverse effects of noise in data transmission systems.
   - 6.9 Outlines the basic advantages of fibre-optic type communication paths in 'noisy' environments.
   - 6.10 Explains the term 'multiplexing' as applied to data channels.

[G] MICROCOMPUTER CONTROL AND INTERFACING

7. Describes the use of a microprocessor based computer system as a robot controller.
   - 7.1 Distinguishes between a microprocessor and a microcomputer.
   - 7.2 Appreciates the need for hardware and software in a microcomputer system.
   - 7.3 Describes the composition of a microcomputer system as a collection of L.S.I. circuits which are interconnected by data, address and control busses, including:
     (a) CPU and associated clock;
     (b) memory devices (RAM, ROM and backing store);
     (c) input and output devices.
   - 7.4 Explains the speed, signal level and timing disparities which exist between the computer and the peripheral devices attached to it.
   - 7.5 Explains the need for an interface between the computer and its peripherals to accommodate the disparities of 7.4.
   - 7.6 Explains the facilities provided by a C.P.U. including:
     (a) arithmetic; (c) data movement;
     (b) logic; (d) branching.
   - 7.7 Describes the manner in which the computer executes stored programs consisting of sequences of basic functions.
   - 7.8 Distinguishes between parallel and serial data transfers.
   - 7.9 Describes the variety of L.S.I. chips available for use in parallel and serial microcomputer interfaces.
   - 7.10 Describes the basic principles of software polling and interrupts as two methods of peripheral communication.
   - 7.11 Explains that actuators and sensors can be treated as peripheral devices by the microcomputer.
   - 7.12 Describes the way in which the processor, using suitable interfaces, can:
     (a) control a number of two-state devices such as solenoid valves;
     (b) interrogate a number of two-state switching devices.
   - 7.13 Describes the way in which the processor can, using D-A and A-D converters:
     (a) control the voltage applied to a servomotor;
     (b) measure the voltage across a potentiometer.
   - 7.14 Describes the way in which the processor can provide drive signals for stepping motors and pulse-width modulated servo-motors.

[H] LANGUAGES AND PROGRAMMING

8. Distinguishes between different levels of programming language and describes some of the features of special purpose robot control languages.
   - 8.1 Describes the nature of a machine code/assembly language program.
   - 8.2 Describes the relative advantages and disadvantages of high level languages.
   - 8.3 Describes the basic functions of operating systems, compilers/interpreters and editors.
   - 8.4 Lists some of the more common high-level languages and typical applications.
   - 8.6 Explains the relationship between the requirements of real-time operation and the choice of language used.
   - 8.7 Explains how special purpose robot arm languages may be implemented through another high level language.
   - 8.8 Lists some of the features offered by simple arm control operating systems, such as:
     (a) direct control of joints using joystick or keypad;
     (b) teach and learn modes;
     (c) user written program sequences which include:
     (i) continuous movements such as rotation;
     (ii) changes in position;
     (iii) input/output functions and time delays.
   - 8.9 Programs a small robot arm device offering suitable facilities.
   - 8.10 Describes additional features offered by more sophisticated industrial arm control operated systems, including:
     (a) different co-ordinate reference frames;
     (b) different reference points;
     (c) point-to-point operation;
     (d) trajectory control, continuous path working, target tracking;
     (e) adaptive programming;
     (f) work space mapping.

[I] TYPICAL ARMS AND APPLICATIONS

9. Describes typical industrial arms.
   - 9.1 Surveys some major robot manufacturers' products.
   - 9.2 Describes the principal features of one particular production arm, taking into account such points as:
     (a) types of actuators;
     (b) type of controller;
     (c) architecture;
     (d) language and software facilities;
     (e) intended applications;
     (f) interfacing facilities;
     (g) performance specification.
   - 9.3 Identifies the particular operational features of robotic arm devices that make them suitable for such tasks as
     (a) die casting and
     (b) welding and paint spraying;
     (c) press and machine tool loading;
     (d) palletising;
     (e) assembly;
     (f) packaging.

[J] ROBOTS AS SYSTEM COMPONENTS

10. Describes the utilisation of robot arms as part of a production/manufacturing process.
    - 10.1 Explains the role of an arm as only one part of a production process.
    - 10.2 Explains that providing an arm may be the least costly step in the task automation process.
    - 10.3 Describes the possible adjustments necessary to adapt the task, associated equipment and personnel to provide a suitable working environment for a robot.
    - 10.4 Describes examples of manufacturing/assembly processes which consist of several robotic devices and other machines working under the hierarchical control of a larger computer.
    - 10.5 Explains the concept of a manufacturing cell.

[K] CURRENT DEVELOPMENTS

11. Identifies some current developments within the rapidly growing field of robotics.
    - 11.1 Describes recent developments in the use of robotic vision for pattern recognition.
    - 11.2 Describes developments in grippers and in tactile sensing.
    - 11.3 Describes man-robot voice communication methods.
    - 11.4 Describes advances in artificial intelligence.
    - 11.5 Describes techniques for increasing work space by increasing mobility.
    - 11.6 Identifies the developments needed to automate typical production processes.

[L] PRACTICAL WORK

12. Gains experience in operating a typical robot arm.
    - 12.1 Operates a robot arm under manual control to determine its range of movements and operating speed on each axis.
    - 12.2 Operates each of the arm movements independently under program control.
    - 12.3 Programs the arm to perform a simple sequence of movements using the 'teach' mode.
    - 12.4 Investigates performance parameters, such as speed, accuracy, repeatability and working volume.
    - 12.5 Programs the arm to follow a linear path between two arbitary points.
    - 12.6 Programs an arm to perform a simple task requiring an external sensor such as a proximity switch.

[M] ECONOMICS

13. Examines the economics of industrial robots.
    - 13.1 Explains the advantages gained from a robot installation in terms of:
      (a) manpower saving;
      (b) improved productivity;
      (c) capability of sustained working in hostile environments;
      (d) flexibility of operation;
      (e) product quality.
    - 13.2 Performs simple calculations illustrating the expected return on initial capital investment.
    - 13.3 Describes an example showing the financial implications of robot assembly operations in a manufacturing process.

APPENDIX C

EXAMPLES OF COURSE MODULES

The following give the outlines of three course units prepared by selecting from the objectives bank in ***Appendix B*** *with additions as appropriate to the particular requirements of the course. The numbers in brackets refer to* ***Appendix B.***

Example 1

Robotic Systems (60-hour unit)

Level IV unit in full-time course in electrical and electronic engineering. Other course units includes control theory, microprocessor principles, and power electronics and drives.

1) Architecture (B 2.1–2.9)
2) Drives and Systems
(C 3.1–3.17) (E 5.7–5.21) (F 6.1–6.6) (G 7.4–7.9/7.12–7.14)
3) Grippers and Manipulators (D 4.1–4.6)
4) Robot Environments (J 10.1–10.5)
5) Typical Arms and Applications (I 9.1–9.3)
6) Languages and Programming (H 8.1–8.10)

Example 2

Principles of Robotics and Manipulators (30 hrs)

Level IV half-unit in post-experience course on microprocessor applications and robotics, intended for qualified students wishing to update their knowledge and qualifications.
Prerequisites: a basic knowledge of electrical and electronic engineering equivalent to HC level.

1) Robot Evolution (A 1.1–1.9)
2) Robot Architecture (B 2.1–2.9)
3) Drives and Systems
(C 3.1–3.3/3.12–3.17) (E 5.7–5.20) (G 7.4–7.9/7.12–7.14)
4) Grippers and Manipulators (D 4.1–4.2)
5) Applications (I 9.1–9.3)

Example 3

Robotics (two 20-hour short courses)

Evening courses intended for mature students with an engineering background. A knowledge of control and microprocessor principles is required for the second course. The courses are not examinable and are supplemented by written material.

Introduction to Robotics

1) Introductory survey (A 1.1–1.9)
2) Architecture (B 2.1–2.9)
3) Hydraulic and Pneumatic Actuators (C 3.1–3.7)
4) Electrical Actuators (C 3.8–3.17)
5) Grippers and Manipulators (D 4.1–4.6)
6) Data Acquisition (F 6.1–6.10)
7) Typical Arms and Applications (I 9.1–9.3)
8) Practical Work (L 12.1–12.6)

Robotic Devices – Control and Applications

1) Arm Control (E 5.1–5.21)
2) Microprocessor Control and Interfacing (G 7.1–7.14)
3) Languages and Programming (H 8.1–8.10)
4) Industrial Applications (J 10.1–10.5)
5) Current Developments (K 11.1–11.6)
6) Industrial Arms (visits)

APPENDIX D

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(4) CHIROUZE, M. & COIFFET, P. *An introduction to robot technology* IFS Publications 1983 (similar book also by Kogan Page).
(5) ENGELBERGER, J. F. *Robots in practice: management and applications of industrial robots* Kogan Page & Avebury Pub. Co. 1980.
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(11) HILL, R. J. & PROBERT, P. J. *Microprocessor control of a robot arm* in *Int. J. Enging. Educ. 20* pp303-316 1983 (use of a small arm for robotics teaching).
(12) *Robotics and industrial electronics* Heathkit Educational Systems 1982.
(13) *Computerised robots:* Course 375, Integrated Computer Systems, Pebblecoombe, Tadworth, Surrey.

Some publishers are producing a range of magazines and textbooks on robotics; these include *IFS (Publications) Ltd, 35-39 High Street, Kempston, Bedford, MK42 7BT* and *Kogan Page Ltd, 120 Pentonville Road, London N1.* Other sources of information are given in Reference 2, and in the textbooks above. Many magazines and periodicals devote sections to robotics.

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Objectives

The objects for which **The Further Education Unit (FEU)** is established are to promote, encourage and develop the efficient provision of further education in the United Kingdom and for that purpose:

(a) to review and evaluate the range of existing further education curricula and programmes and to identify overlap, duplication, deficiencies and inconsistencies therein;

(b) to determine priorities for action to improve the provision of further education and to make recommendations as to how such improvement can be effected;

(c) to carry out studies in further education and to support investigations of and experimentation in, and the development of further education curricula and to contribute to and assist in the evaluation of initiatives in further education;

(d) to disseminate and publish information and to assist in the dissemination and publication of information about recommendations for and experiments and developments in further education.

The publications in this series of *Reports* are intended to inform teachers and others and to stimulate professional discussion about matters of concern to the FE service. The views expressed are not necessarily those of the Unit's Board of Management.

About this publication

The increasing use of robotic arms in industry implies the training of substantial numbers of personnel and college and curriculum bodies alike are developing ways of introducing robotics into the curriculum. A further justification for the introduction of robotic arms into FE curricula as devices in their own right is that they *'provide an excellent illustration of most of the major principles underlying automation, particularly the industrial application of microprocessors'.*
Against a fast-developing background, this report examines the problems of setting up broad-based introductory technician training courses in robotics, considers the suitability of low-cost robotic arms for such courses, and compares some of those available in terms of cost, construction and facilities offered. Suitable teaching material is outlined in the form of a bank of objectives, and examples of course modules (for post experience short courses as well as for conventional technician training courses) are included. The report suggests that teaching requirements at the introductory level may be met by integrating existing material from a wide variety of disciplines, and that colleges with mechanical and electrical engineering and computing departments should be able to offer introductory units including robotics without substantial staff retraining. New technology generally requires the integration of a wide range of disciplines, including mechanics, electronics, production, computing and maintenance, and the robotic arm is a good example of a multi-disciplinary topic area which facilitates this integration.

Other publications available

A FRAMEWORK FOR ACTION IN IT

Information technology in further education

A framework for action in IT attempts to construct a working definition of IT, to review some FEU work in this field, and to suggest a model for curriculum policy and development. The aim in publishing this 'framework' – and its accompanying 'map' of FEU-linked projects in the IT area – is to present a coherent picture of work in IT which may assist an institution and its teachers to formulate an IT policy, avoiding duplication of effort and wasteful use of resources. In particular, it is hoped that the IT 'map' will be found by colleges to be a useful device for planning policy, determining priorities, allocating resources, marketing their expertise and identifying staff development and support needs – in fact for constructing their own 'framework for action'. *(July 1984)*

TOWARDS THE ELECTRONIC OFFICE

Christine Disney, *Computer Consultant*

A timely overview of the curricular implications of new technology for business education and training. The early sections of the report describe a growing awareness and use of information technology by industry and commerce. The later sections look at the ways in which the training and education systems are reacting to a rapidly changing situation. *(September 1983).*

INFORMATION TECHNOLOGY IN FE

A survey of IT policy and of current practice in a sample of colleges

This report gives the key findings of a survey of twenty colleges – all actively engaged in developing their IT expertise and resources. It shows that many teachers do not appreciate the relevance of the computer to their work, and reveals that few colleges have an effective and structured approach to IT in terms of staffing, equipment or application. The report highlights various factors needing urgent attention, as well as providing information about the usage of IT by departments, the typical courses available, and a number of case studies of IT development and application successfully achieved by individual college departments. *(April 1984).*

COMPUTER AIDED DESIGN IN FE

Some suggestions on the inclusion of CAD topics in Mechanical Engineering courses.

Peter Ingham
City of Birmingham Polytechnic

This document is intended to give guidance to those concerned with the introduction of Computer Aided Design (CAD) into technical curricula. Whilst specially related to mechanical engineering, it should also prove useful to those in other disciplines. The author considers as inevitable the widespread adoption of CAD by British industry. Further education will, therefore, have an obvious role to play in CAD development, if it is to remain a significant contributor to technological updating. *(November 1982).*

To obtain FEU publications

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